

Abstract for Application of the Life Safety Code to an Historic Test Stand

NASA has assessed alternatives to refurbish existing launch vehicle modal test facilities as opposed to developing new test facilities to meet the demands of a very fiscally constrained test and evaluation environment. Trades were performed with key selection criteria to ensure that appropriate levels of occupant safety are incorporated into test facility design modifications. In preparation for the ground vibration tests that were to be performed on the Ares launch vehicle, the Marshall Space Flight Center (MSFC) Flight and Integrated Test Office (FITO) organization evaluated the available test facility options which included the existing mothballed structural dynamic test stand (TS) at MSFC (TS4550) used by Apollo and Shuttle, alternative ground vibration test facilities at other locations, and the construction of a new dynamic test stand. After an exhaustive assessment of the alternatives, the results favored modifying the TS4550 because it was the lowest cost option and presented the least schedule risk to the NASA Constellation Program for Ares Integrated Vehicle Ground Vibration Test (IVGVT). As the renovation design plans and drawings were being developed for TS4550, a safety concern was discovered with the construction of the test stand originally built for the Apollo program and renovated for the Shuttle program, in that the original design was completed before NASA's adoption of the currently imposed safety and building codes per National Fire Protection Association Life Safety Code [NFPA 101] and International Building Codes. The initial Constellation Ares FITO assessment of the design changes, required to make TS4550 compliant with current safety and building standards, identified a significant cost increase and schedule impact. An effort was launched to thoroughly evaluate the applicable life safety requirements, to examine the context in which they were derived, and then determine a means by which the TS4550 modifications could be made within budget, on schedule, and still provide the occupants with appropriate levels of safety. The results of this study showed that TS4550 could be made compliant within reasonable cost and schedule impacts because there were safety processes and operational limitations that could be put in place to meet the safety codes and concerns of the Fire Marshall.

APPLICATION OF THE LIFE SAFETY CODE TO A HISTORIC TEST STAND

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ABSTRACT

NASA has conducted a study to assess alternatives to refurbishing existing launch vehicle modal test facilities as opposed to developing new test facilities to meet the demands of a very fiscally constrained test and evaluation environment. The results of this study showed that Marshall Space Flight Center (MSFC) Test Stand (TS) 4550 could be made compliant, within reasonable cost and schedule impacts, if safety processes and operational limitations were put in place to meet the safety codes and concerns of the Fire Marshall. Trades were performed with key selection criteria to ensure that appropriate levels of occupant safety are incorporated into test facility design modifications. In preparation for the ground vibration tests that were to be performed on the Ares I launch vehicle, the Ares Flight and Integrated Test Office (FITO) organization evaluated the available test facility options, which included the existing mothballed structural dynamic TS4550 used by Apollo and Shuttle, alternative ground vibration test facilities at other locations, and construction of a new dynamic test stand. After an exhaustive assessment of the alternatives, the results favored modifying the TS4550 because it was the lowest cost option and presented the least schedule risk to the NASA Constellation Program for Ares Integrated Vehicle Ground Vibration Test (IVGVT). As the renovation design plans and drawings were being developed for TS4550, a safety concern was discovered – the original design for the construction of the test stand, originally built for the Apollo Program and renovated for the Shuttle Program, was completed before NASA's adoption of the currently imposed safety and building codes per National Fire Protection Association Life Safety Code [NFPA 101] and International Building Codes. The initial FITO assessment of the design changes, required to make TS4550 compliant with current safety and building standards, identified a significant cost increase and schedule impact. An effort was launched to thoroughly evaluate the applicable life safety requirements, examine the context in which they were derived, and determine a means by which the TS4550 modifications could be made within budget and on schedule, while still providing the occupants with appropriate levels of safety.

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INTRODUCTION

During the course of the NASA Constellation Program (CxP), test data was acquired to support the design, development, and certification of the Ares I and V launch vehicles. To support acquisition of this data, it was necessary to construct new test facilities and upgrade and modify existing test facilities. One validation test required to support the development of the Ares I launch vehicle was the Ares I Integrated Vehicle Ground Vibration Test (IVGVT). To accommodate this testing, CxP officials decided to renovate the historical dynamic test stand at MSFC. This test stand was originally built to accommodate dynamic testing of the Apollo V launch vehicle and was subsequently renovated to accommodate testing of the Space Transportation System (Space Shuttle). Both of these prior renovations preceded NASA's adoption of the National Fire Protection Association Life Safety Code (NFPA 101), an internationally recognized building code which establishes the minimum occupant protection requirements based on the activities performed by the occupants and the level of hazard exposure that the public is willing to accept for the occupants. NFPA 101 requirements establish occupant protective measures such as maximum egress path lengths, exit sign locations, and determining if a fire protection system is necessary to protect the occupants. As the egress paths for the test stand were to be modified, it was determined that the building needed to be brought into compliance with the 2006 NFPA 101. To keep project costs to a minimum and prevent delays in test operations, alternative methods were explored to provide the test stand occupants with appropriate levels of safety while reducing the cost and schedule impacts to the program. This paper will examine how the IVGVT team came together with other NASA and MSFC organizations to solve the issues associated with applying the current life safety code to the refurbishment of a historic test stand, particularly looking at the applicable life safety requirements, the context in which they were evaluated, and the means by which occupant safety was ensured.

TEST PROGRAM CONTEXT

In early 2006, the MSFC Engineering Directorate supported the new CxP, Ares Projects, Vehicle Integration Office (VIO) in preparing an evaluation of the engineering test programs that had been historically performed to qualify and human-rate historic launch vehicles. One of the past test programs identified as being necessary was the structural dynamic testing of the fully integrated launch stack to validate the structural models and the avionics system. Based on the outcome of consultations between the VIO and the Engineering Directorate, the MSFC Engineering Management Council (EMC) decided that it would be prudent to begin bringing the historic MSFC Test Stand 4550 (TS4550) out of mothball status.

The MSFC EMC established preliminary facility requirements based on the assumption that the first structural dynamic test to be performed in TS4550 for the CxP would be the evaluation of an Ares I protovehicle. This test program would function as a final verification of the structural dynamics before the protoflight vehicle was sent to Kennedy Space Center (KSC) for the Ares Demonstrator Flight Test 1 (ADFT-1), based on the understanding that the Ares I development program would launch a series of protoflight vehicles to validate key development milestones as was done during the Apollo Program. The original facility requirements incorporated into the Construction of Facilities (CoF) Project were based on the needs of this other project.

After responsibility for the development of a master test program was transferred to the new CxP, Ares Projects, FITO in the fall of 2006, it was determined that CxP funding could not support as many test flights as the Apollo Program; therefore, any structural dynamic testing for test flight launch vehicles would occur at KSC as done with Ares I-X on the mobile launch platform.

Also in the fall of 2006, the FITO Manager received a test data request from the VIO. Once CxP managers decided to support the human-rating of the Ares I launch vehicle by testing and validating the structural finite element models upon which the design was based, the FITO Manager determined the most appropriate way to acquire this data was to conduct a structural dynamics test of a production Ares I. This test program became known as the IVGVT. The FITO Manager selected TS4550 as the test facility after evaluating the available test facilities. In response to that selection, the Engineering Directorate re-evaluated the facility requirements it had prepared for the ADFT-1 structural dynamics test to accommodate the much more complex IVGVT.

ORGANIZATIONAL CONTEXT

While this paper primarily discusses how NASA ensured the safety of the occupants of a previously mothballed historic test stand, the organizational context for the decision-making process must be introduced so that the means by which the life safety requirements were determined and a solution was iterated can be understood. The authors wish to point out that all organizations were passionate about providing the occupants with an appropriately safe working environment to prepare the test article and execute the test program. While some difficulties were encountered in arriving at a solution due to an initial lack of a common lexicon and an unfamiliarity regarding the roles and responsibilities of the other organizations in preparing the facility, the various organizations worked together to achieve a “win-win” for MSFC and the CxP.

The overall IVGVT Task was led and funded by the CxP Ares Projects FITO. The FITO Structures, Environments, and Vibrations Test (SE&VT) Lead acted as the IVGVT Task Lead for the life of the Task. As the representative of the FITO Chief Engineer and the FITO Project Manager, respectively, the IVGVT Task Lead set the top-level test goals and requirements and managed the Task funding as part of the overall Ares Projects budget. In addition, the IVGVT Task Lead, while delegating responsibility for test preparations and the test operations to the MSFC Engineering Directorate, retained the responsibility for communicating with the Ares Elements and acquiring the test articles and Ground Support Equipment (GSE). The IVGVT Task Lead was also the point of contact between the FITO and the engineering analysts supporting the Ares Vehicle Integration Office (principally from the MSFC Engineering Directorate, Structural Design and Analysis Branch (SD&A Branch)), and the Ares Projects Office Systems Engineering & Integration (SE&I) Office.

The work associated with test preparation and test operations was performed for the FITO by the MSFC Engineering Directorate and was led by a project manager from the Spacecraft and Vehicle Systems Engineering and Integration Division, Systems Test and Flight Evaluation Branch (ST&FE Branch). (For purposes of this paper, the title Test Conductor – the project manager’s original title - will be used throughout.) The Test Conductor was the point of contact between the MSFC Engineering Directorate and the IVGVT Task Lead, as well as the point of contact between the Task and the MSFC Facilities Office. The Test Conductor was responsible for obtaining all necessary Special Test Equipment (STE) and the test facility, as well

as preparing the test stand, integrating the test article upon delivery, de-stacking the test article after conclusion of test operations, closing out the test stand, and delivering the test data to the IVGVT Task Lead.

Within MSFC Engineering Directorate, the Engineering Test Laboratory, the Structural Dynamics Test Branch (SD Test Lab) had responsibility for preparing the test article and conducting test operations. This effort was led by the Lead Test Engineer, who reported to the Test Conductor. The Lead Test Engineer was supported in these efforts by test engineers from other Branches within the Test Lab. In regards to TS4550, the Lead Test Engineer was responsible for identifying and communicating to the Test Conductor all facility requirements derived from the test requirements promulgated from the FITO.

The Test Conductor was supported in the preparation of the test stand and development of facility requirements by personnel from the Special Test Equipment Design and Manufacturing Branch (STE Design Branch). Regarding TS4550, STE Design Branch personnel prepared a demolition plan for the Space Shuttle STE, which had been abandoned in place after conclusion of the STS Mated Vehicle Ground Vibration Test (MVGVT) in 1979. They also identified and communicated to the Test Conductor and FITO any facility requirements related to the IVGVT STE (e.g., electrical power requirements). Once the demolition plan was prepared, responsibility for demolition work was turned over to the Lead Test Engineer, who had delegated the demolition plan execution to the Propulsion Systems Test Branch (Propulsion Test Lab).

The Test Conductor was supported in the development of stacking, integration, and de-stacking operations by the Propulsion Test Lab and the MSFC Engineering Directorate, Ground Operations and Logistics (GO&L) Branch. In regards to TS4550, the Propulsion Test Lab and the GO&L Branch identified the crane requirements and any building modifications necessary to accommodate lifting the hardware into and out of the building.

One of the Test Conductor's responsibilities was securing use of the test stand and communicating the Engineering Directorate's facility requirements for the test stand to the MSFC Facilities Office. The Test Conductor was the official point of contact between the IVGVT Task and the Facilities Office; however, as funding for the construction effort was allocated from FITO, it was necessary for the IVGVT Task Lead and other members of FITO to interface directly with representatives of the Facilities Office.

As will be elaborated upon further, prior to the initiation of the IVGVT, the Facilities Office was preparing a CoF Project for the Center to maintain TS4550 as a core capability facility. The design of this CoF Project had been contracted to an Architecture and Engineering (A&E) firm, which, it should be noted, was initially only to determine what work would be necessary to bring TS4550 up to current codes (a prescriptive design). Once the Test Conductor communicated the IVGVT facility requirements to the Facilities Office, the CoF Project baseline was revised to incorporate the stated requirements. Upon review, it was determined that there were significant costs associated with a prescriptive design. To meet the needs of the Engineering Directorate, the A&E firm worked with the Facilities Office and representatives of the Engineering Directorate, the FITO, and the MSFC Safety and Mission Assurance (S&MA) Directorate to prepare a performance-based design, which would provide adequate risk mitigation while remaining within the Program's financial constraints.

In support of the Engineering Directorate's efforts to prepare TS4550 for use in the IVGVT, the MSFC S&MA Directorate, Industrial Safety Branch, conducted a code review of the TS4550. The Industrial Safety Branch Chief, also known as the MSFC Fire Marshall, is the Authority Having Jurisdiction (AHJ) for all life safety and fire codes and standards at MSFC. The MSFC Fire Marshall was the final approving authority for the facility design. To approve the final design, the Fire Marshall required documentation regarding the hazards and the risk mitigations that were being implemented in lieu of the prescriptive code requirements. . To facilitate the necessary information exchange of critical architectural engineering information between representatives of the Facilities Office, the Fire Marshall, the Test Conductor, and the IVGVT Task Lead, the IVGVT Task Lead engaged a consultant with a background in aerospace engineering, architectural engineering, and fire protection engineering to facilitate the establishment of a common lexicon between all parties and clarify the goals and needs of all organizations.

A diagram of how the derived facility requirements flowed between the organizations listed above, shown in Figure 1, shows the distinct organizations involved in developing and iterating out the facility requirements as related to life safety. Note that this diagram does not represent the Task organizational hierarchy, nor does it capture all activities that occurred during the IVGVT Task. Since the IVGVT was canceled in October 2010 due to a restructuring of the Constellation Program with the IVGVT closing out during the next year.

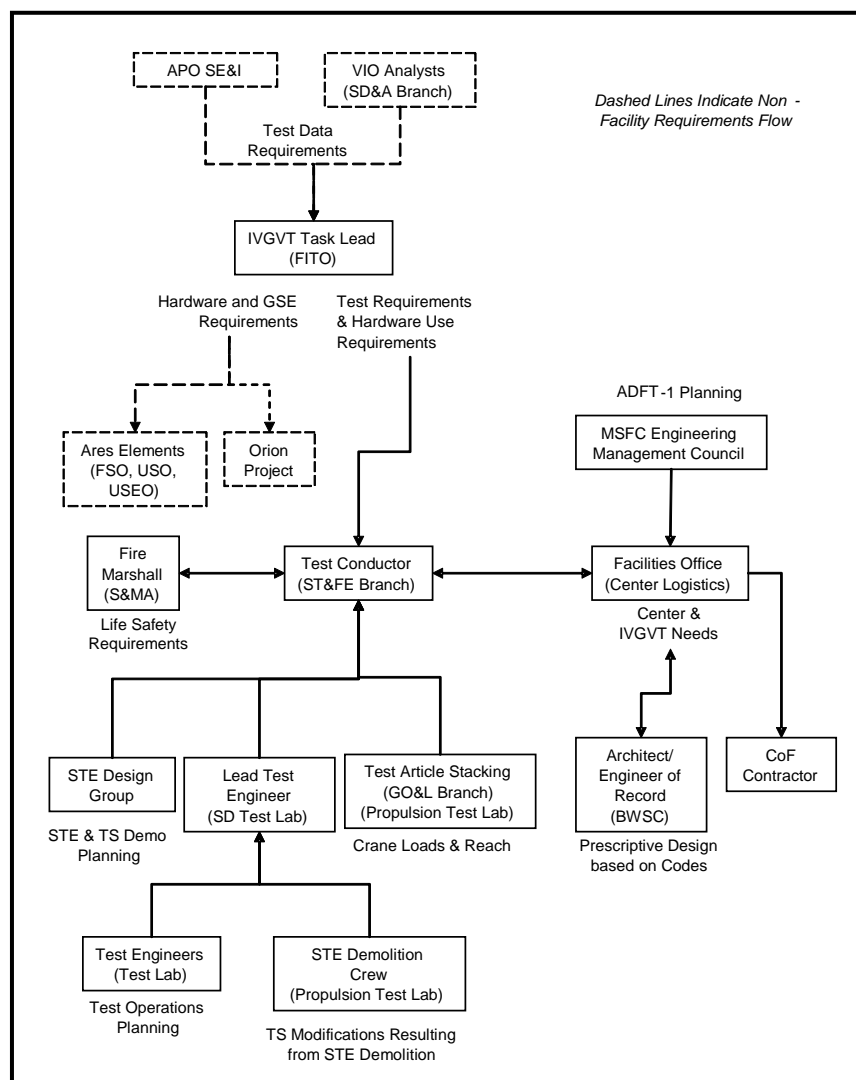


Figure 1: Facility Requirements Flow

HISTORICAL PERSPECTIVE

In the fall of 2006, the NASA CxP, Ares Projects Office (APO) determined that the Ares I structural dynamics mathematical models would be principally validated through test data obtained from a modal survey of the integrated vehicle. The FITO was assigned responsibility for executing this test, designated as the IVGVT. The program and technical requirements of the IVGVT are described in the NASA document *CxP 72234, Ares I IVGVT Task Plan*, and are outside the scope of this document. Part of the IVGVT Task Lead's responsibilities for preparing for the IVGVT included determination of the best location for the test, as well as evaluating the existing, mothballed structural dynamic test stand at MSFC (TS4550), alternative locations for the test, and the costs associated with constructing a new dynamic test stand either at the same location or a new location. The IVGVT Task Lead determined that the best course of action was to modify TS4550, the least costly option with the least schedule risk to the Program.

TS4550 was originally built in 1964 for the Apollo Program and then renovated in 1977 – 1978 to accommodate dynamic testing of the Space Shuttle (see Figure 2). Approximately 28 years lapsed between close-out of Space Shuttle testing and the commencement of the IVGVT, during which time the building was effectively mothballed and unoccupied.



Figure 2: Space Shuttle Orbiter Being Removed from TS4550 (1978)

BUILDING DESCRIPTION

TS4550, a 360-foot tall building consisting of all steel construction, is divided into 15 levels (24 feet per level) (see Figure 3). The building footprint is 100 x 125 feet with an open interior (see Figure 4). The building has a 200-ton derrick crane mounted on the northwest corner of the roof, bringing the overall height to 425 feet.

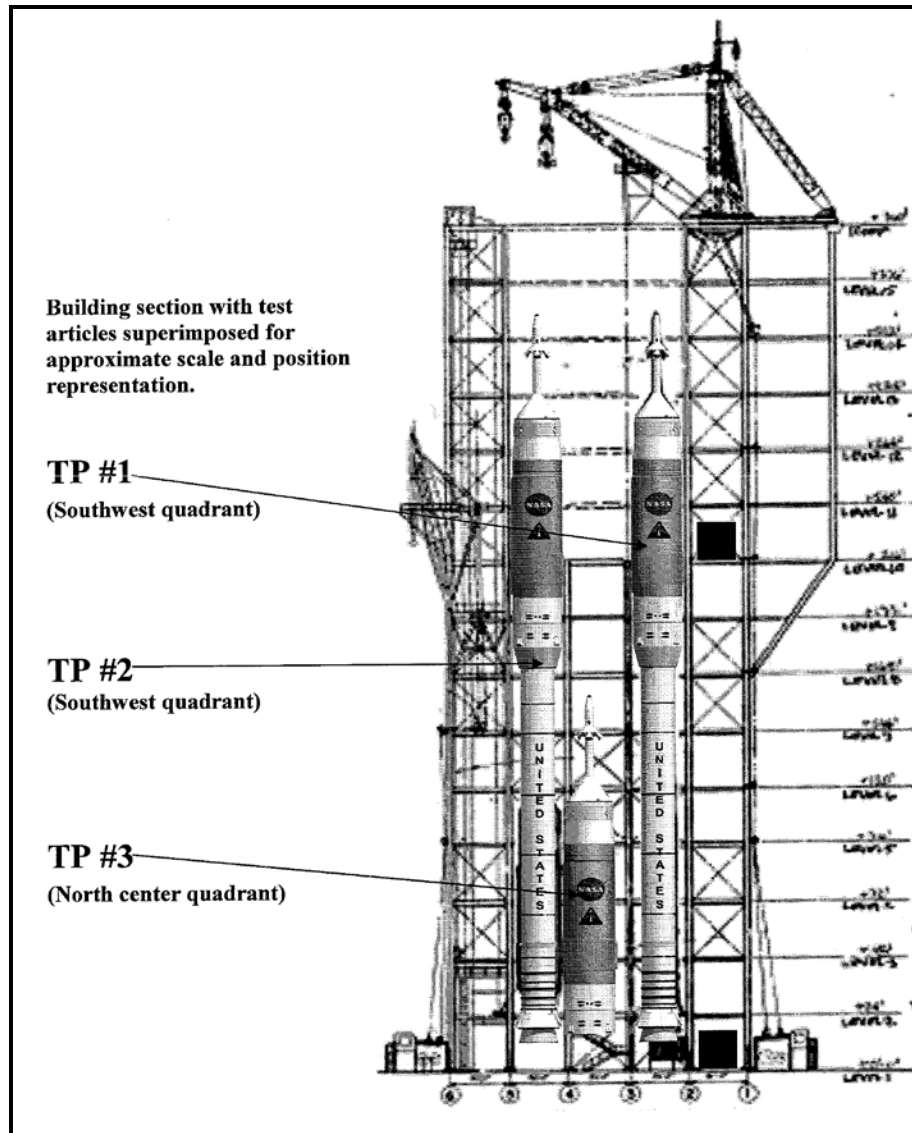


Figure 3: Test Stand 4550 – Section at Column Line A Looking South

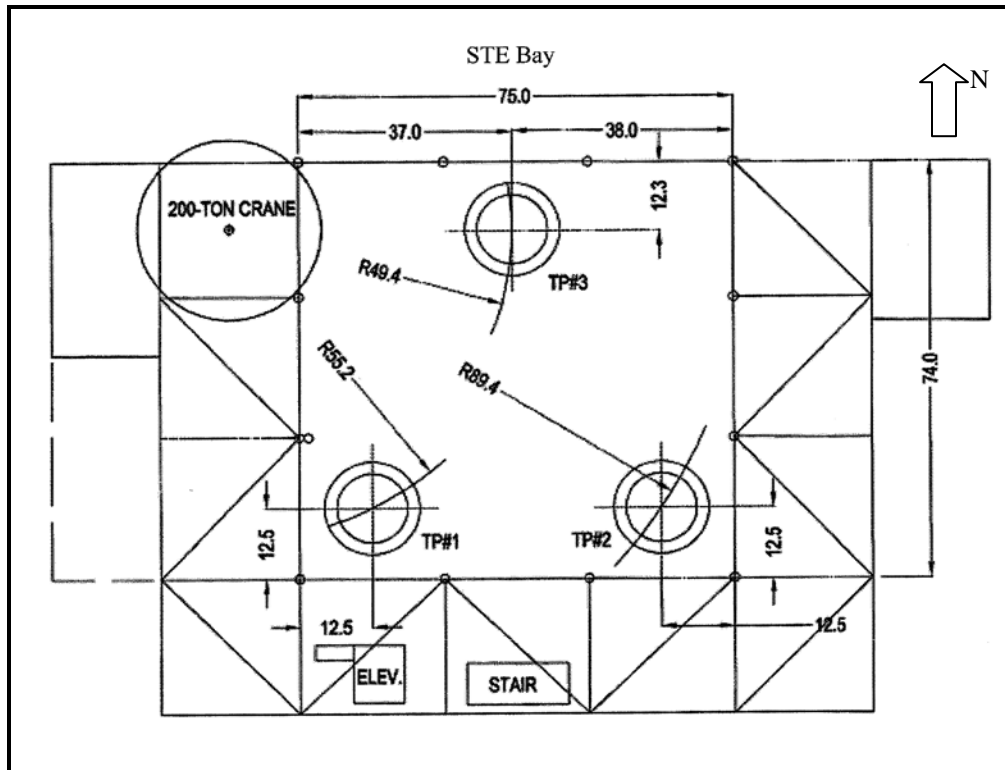


Figure 4: Test Stand 4550 – Elevation 0'-0" (Level 1)

The majority of the north wall consists of a 144 foot tall x 75 foot wide door. The lower edge of the door is at the 216 foot level and extends to the roofline. The walls of the lowest level are open. Above the first level, the building's exterior walls are clad with heavy gauge corrugated sheet metal, and no insulation or interior finish other than paint is present. Although there are translucent fiberglass panels located on the exterior of the building to allow some ambient light to enter the building, there are no operable windows or exterior doors above the first level.

The building roof consists of steel trusses capped by steel plate and raised seam sheet metal roofing material. The roof between column lines B2-B5 and E2-E5 is removable in three panel sections (total area 75 x 75 feet). Nominally, these panels are only removed for test article stacking operations and are in place during test operations. The interior consists of 25-foot wide spans of open steel framing on the south, east, and west sides. Connection beams span the north wall up to the 216-foot level, above which is the movable door. There is no framing spanning the central portion of the building, leaving it unobstructed for the installation of test articles. While working platforms are located at all levels of the building, there are no full-width floors. The core of the building from column lines B2-B5 to E2-E5 is open from the ground level to the roof. These features effectively cause the building interior to function as an atrium with chimney effects.

Upon initiation of the IVGVT Task, the central portion of the building had temporary platform structures in it to facilitate access to the MVGVT test articles for Shuttle. These temporary platforms were considered Special Test Equipment (STE) - not an inherent element of the facility itself - and were removed as part of the facility modifications. Three existing small rooms located on the second, ninth, and tenth levels, which were to be removed as part of the facility

modifications, are the only interior partitions in the building. Figure 5 shows the second level, which had the largest small room. The IVGVT Task was terminated before these rooms could be removed.

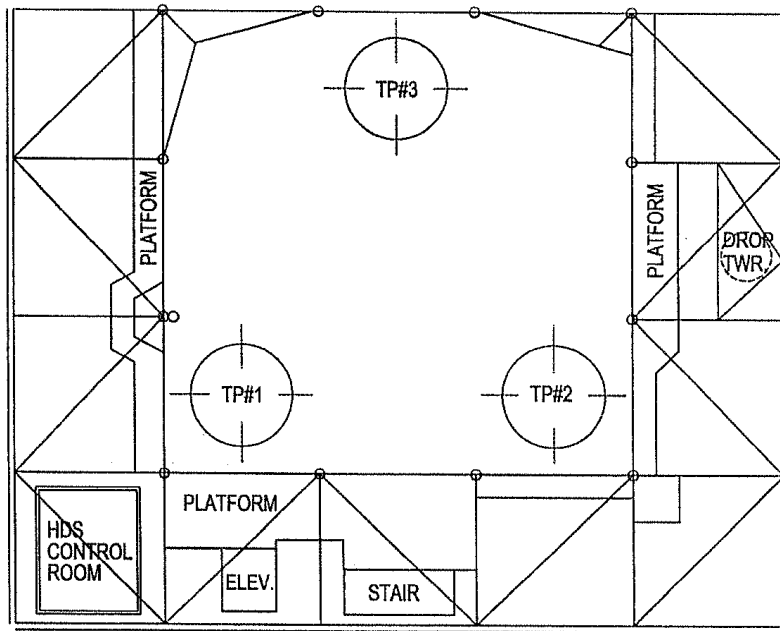


Figure 5: Test Stand 4550 – Elevation 24'-0" (Level 2)

SUMMARY OF TECHNICAL ISSUES

After the completion of the Space Shuttle dynamic testing, TS4550 was mothballed and the STS STE was abandoned in place, including the temporary work platforms located in the core of the building. Figure 6 shows the STS STE configuration during the Shuttle dynamic testing and represents the building configuration at the inauguration of the IVGVT renovation effort. It was necessary to remove this STE before installing Ares I-specific work platforms in support of the IVGVT. These alterations of the egress paths resulted in the work associated with upgrading TS4550 being considered a modification under the building codes; therefore, all modifications to the building had to comply with the currently adopted building codes.

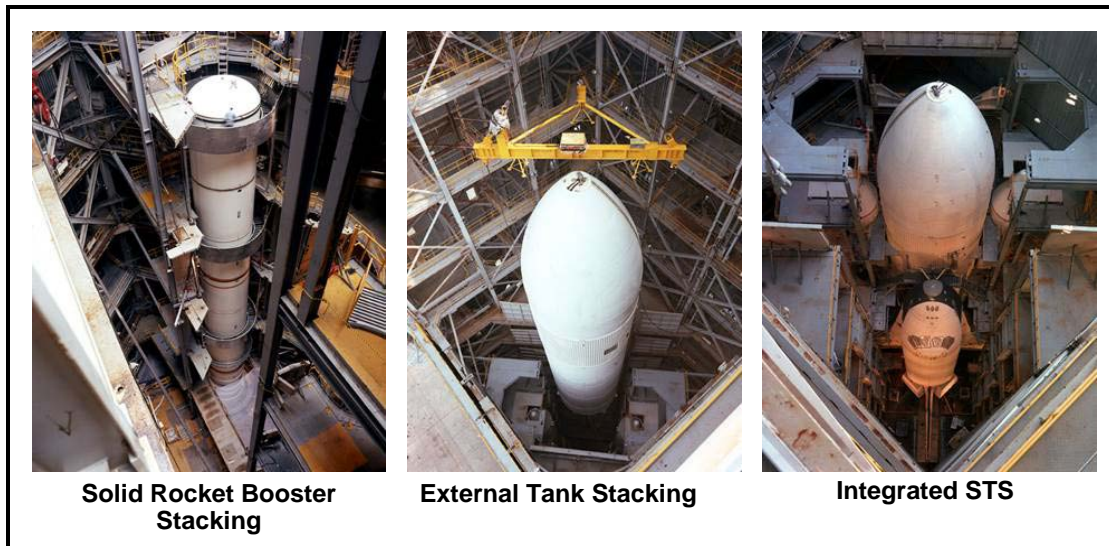


Figure 6. Space Shuttle Elements in MSFC Test Stand 4550

CONSTRUCTION OF FACILITIES PROJECT SCOPE

In January 2006, the MSFC Facilities Group received the periodic Facility Condition Assessment (FCA) of TS4550 from their support contractor. The FCA determined that a number of repairs were necessary to maintain the building in the condition in which it was left at the end of Space Shuttle dynamic testing and to preserve TS4550 as a core capability of MSFC ¹.

A CoF project was inaugurated to resolve several FCA-identified issues that were the result of TS4550 being mothballed for approximately 28 years. The MSFC Facilities Group engaged an A&E firm to prepare and execute this CoF project, which, including construction and commissioning, would ultimately run in parallel to the MSFC Engineering Directorate's project which modified the building to accommodate the IVGVT. During the early design phases of the CoF project, other activities were added to the project scope to expand the capability of the facility.

The CoF activities specifically driven by life safety requirements included upgrading the fire alarm system, adding emergency lighting, and improving the egress path lighting conditions. Other CoF repairs and renovations included:

- Repairs to the roof membrane,
- Repairs to the roof-mounted derrick crane's structural load path,
- Renovation of the derrick crane's control system,
- Repairs to the personnel elevator's controls, and
- Renovation of the building's electrical system.

These repairs were not driven by life safety requirements and will not be addressed further in this document.

BUILDING CODES

As the egress paths for TS4550 were to be modified as part of the CoF project, it was necessary for the Facilities Office to determine which building codes were applicable. NASA Standard 8719.11 §6.1 states that "All NASA buildings shall comply with the following:

1. Appropriate provisions of NFPA 101 (Requirement).
2. Applicable State and local building codes (Requirement)."

In May 2007, as part of the CoF project, the A&E firm prepared and submitted to the Facilities Office a Project Criteria Document (PCD), which included a building code assessment ². The A&E firm determined that the applicable building codes were:

- 2003 International Building Code (IBC)
- 2003 International Fire Code (IFC)
- 2003 NFPA 13: Standard for the Installation of Sprinkler Systems
Note: The correct edition was 2002 which was superseded by the 2007 edition subsequent to initiation of the project.
- 2003 NFPA 20: Standard for the Installation of Stationary Pumps for Fire Protection
- 2004 NFPA 72: National Fire Alarm and Signaling Code
Note: The correct edition was 2002 which was superseded by the 2007 edition subsequent to initiation of the project.
- 2003 NFPA 101: Life Safety Code
Note: The correct edition was 2006 which superseded the 2003 edition prior to submission of the PCD.
- NASA Safety Standard 1740.11: Safety Standard for Fire Protection
Note: NSS 1740.11 (1993) was superseded in 2000 by NASA Standard 8719.11: Safety Standard for Fire Protection. The 2006 revision of NASA-STD-8719.11 was current at the time the PCD was prepared.

As TS4550 was constructed before the adoption of the above codes by NASA, the A&E firm also included in the PCD a determination of the building occupancy construction types so that design and construction work performed would be governed by the applicable sections of the above listed codes. It was determined that test stands do not easily fit into the standard building occupancy types described in NFPA 101 and the IBC. Initial inspection of the occupancy types listed in NFPA 101 and the IBC indicated that TS4550 would be governed by the provisions of the Industrial Occupancy type.

During the early facility design reviews, some members of the IVGVT Team expressed the concern that, as TS4550 was a "test stand" and test stands were not specifically mentioned in NFPA 101 or the IBC, the requirements of NFPA 101 and IBC were not applicable. Once it was clarified that NASA Safety & Mission Assurance (S&MA) had proclaimed through NASA Standard 8719.11 that both NFPA 101 and local building codes (in this case the IBC) were applicable, the IVGVT Team expressed the concern that classifying TS4550 as an Industrial Occupancy was inappropriate, due to the facts that:

1. No manufacturing or production of end items would occur in the building;
2. The building configuration (high rise building with a small foot print) was atypical for a manufacturing or production facility;

3. The Occupant Load Factor of 100 square feet per person given by NFPA 101 – Table 7.3.1.2 would result in accommodations for a population that was several orders of magnitudes larger than the maximum probable population of the building.

These concerns necessitated further review of the occupancy type definitions to determine if “test stands” would fall within the scope of another occupancy type. A further review of the codes revealed that “test stands” could possibly fit in the Storage and Business occupancy types. The Storage Occupancy type was considered for three major reasons:

1. The test article would be located in the building for an extended period of time;
2. A Storage Occupancy is typified by large, un-partitioned spaces filled by commodities;
3. A test stand by definition does not include manufacturing or production equipment which typifies an Industrial Occupancy.

After careful review of the applicable codes against TS4550's functions, it was decided that classifying the test stand as a Storage Occupancy was not appropriate for the following reasons:

1. While the volume of the building was large, very few actual items would remain in the building for an extended period of time, resulting in an open style floor plan while Storage Occupancies are typified by a congested floor plan;
2. While there would be very few personnel in the building during test operations, there could be several dozen occupants present during test preparation efforts;
3. There would be a significant amount of active test equipment present in the building (hydraulic fluid pumps, test article support system, data acquisition systems) that are not typical for a Storage Occupancy;
4. There would be a significant number of activities that would be performed in the building that were not typical for a Storage Occupancy. These potential activities include the use of pressurized fluids and gasses, electrical work, hot work (welding), and confined space entries. These potential activities are significantly more involved than the material handling work performed in a typical Storage Occupancy.

Next, the review evaluated the applicability of the Business Occupancy type classification to the test stand, as:

1. The number of potential occupants was higher than normally associated with a Storage Occupancy;
2. No products were to be manufactured or produced in the building.

Ultimately, the Business Occupancy type was rejected for two principle reasons (as such, the application of the Business Occupancy type to TS4550 was not appropriate):

1. Normal business activities are oriented around “pushing paper”. While data is acquired and a preliminary evaluation of the data is performed in a test stand, the work performed by test personnel does not align with that of a typical office worker.
2. A typical Business Occupancy is partitioned into cubicles, offices, conference rooms, and other work spaces which would not be present in the test stand.

Finally, the review evaluated whether the Special Purpose Industrial Occupancy type was applicable. As defined in 2006 NFPA 101 - 3.3.168.8.3:

Special-Purpose Industrial Occupancy. An industrial occupancy in which ordinary and low hazard industrial operations are conducted in buildings designed for, and suitable only for, particular types of operations, characterized by a relatively low density of employee population, with much of the area occupied by machinery or equipment.

This definition corresponded well to the uses intended for TS4550. The building was designed for the structural dynamic testing of large, integrated space launch vehicles. The operations would consist of preparing the test article for testing, conducting structural dynamic response tests, and ultimately breaking down the test article for transportation away from the test stand. The operations in support of the test consisted of pumping a stimulant (water) into the fuel tanks, pressurizing fuel and liquid oxygen tanks with air or nitrogen to low pressures, vibrating the test article at specific locations with low energy shakers, and draining the stimulant after each test sequence. All of the operations could be considered low or ordinary hazards. It was planned to have less than 25 persons in the building during test article preparation and approximately the same number of people during test operations. The number of people involved in the test yielded a low population density across the available floor space. The majority of the space would be occupied by the test article and test support equipment. These factors demonstrated the appropriateness of applying the Special Purpose Industrial Occupancy type to TS4550.

As NFPA 101 and the IBC did not have occupancy types which specifically included “test stands,” and as all other occupancy types were less suitable, it was determined, after careful review and assessment, that the appropriate NFPA 101 occupancy type for TS4550 was Special Purpose Industrial, which is comparable to the IBC occupancy type Factory Industrial F-2 Low Hazard. This decision was concurred with by the MSFC Fire Marshall and by the MSFC Facilities Office.

INITIAL LIFE SAFETY EVALUATION

As TS4550 was to be brought out of mothball status and become a regularly occupied building, the IVGVT Test Conductor asked the MSFC Fire Marshall to evaluate the building to determine if any life safety issues were present. In May 2007, the Fire Marshall submitted to the IVGVT management team³ a Fire Protection Assessment, which independently determined the building occupancy type and identified three life safety issues specific to TS4550. These issues were the required number of egress paths, the enclosure of the existing staircase, and the requirements regarding a fire suppression system.

The first life safety issue identified by the Fire Marshall was that TS4550 only had one means of egress from the building above the first level (elevation 0'-0"). Except under very limited conditions, all sections of NFPA 101 require that occupants have the option to choose between at least two means of egress from an area after a common travel distance is traversed. As can be seen in Figures 4 and 5 of this paper, there is only one means of egress from TS4550 above the first level, since the elevator cannot be counted. This egress consists of an unenclosed, open tread, metal stair.

The MSFC Fire Marshall determined that it would be acceptable for TS4550 to utilize a single means of egress above the first level. The Fire Marshall's rationale for allowing a single means of egress was based on the fact that “due to the facility's open nature, massive volume, and low fire-loading, a fire will be slow developing, quickly identified by occupants, and take a long time to build up dangerous levels of smoke.” The Fire Marshall also determined that he could not identify “a reasonable scenario in which a single exit will not be adequate,” and identified three code exceptions in NFPA 101 which supported this evaluation.

1. NFPA 101 - 40.2.4.1.2: “A single means of egress shall be permitted from any story or section in low and ordinary hazard industrial occupancies, provided that

the exit can be reached within the distance permitted as a common path of travel.” (Table 40.2.5 sets that distance as 50 feet.)

2. NFPA 101 - 11.2.2.4.2: “Open structures occupied by not more than three persons, with travel distance of not more than 200 feet shall be permitted to have a single exit.”
3. NFPA 101 - 11.3.2.4 permits single exits for towers subject to maximum occupancy of 25 persons and other conditions that this facility meets.

While these exceptions were not valid for TS4550, since the common paths of travel were greater than 50 feet, there would be more than three occupants in the entire building, and TS4550 did not meet the definition of a “Tower.” Therefore, the Fire Marshall indicated that, for buildings with limited access and limited occupancy, the life safety community recognizes that it is acceptable to have only a single means of egress.

Three operational factors were also considered by the Fire Marshall in his assessment. First, TS4550 is located in an area of MSFC which is considered a hazardous location; personnel entering the test area would have to be cognizant of the inherent and specific risks associated with the area in which they would be working. Second, the size of the population that would be exposed to any risks associated with a single means of egress was limited to the test operation personnel and escorted visitors. The assumed maximum population was on the order of 20 to 30 people while non-hazardous operations were occurring and a population of less than 10 when hazardous operations were occurring. Third, the building itself was non-combustible and there would be very limited combustible materials brought into the building.

Considering these factors, the Fire Marshall recommended that only a single means of egress was necessary as long as, (1) the population was limited to a maximum of 25 persons, and (2) the combustible loading in the building be strictly limited to what was absolutely required for operations. The MSFC Test Lab and the FITO concurred with this recommendation and the limitations placed upon operations.

The second life safety issue identified by the Fire Marshall was that the existing staircase was not enclosed and separated from the residual of the building. The Fire Marshall identified in his assessment the following requirements from NFPA 101:

1. NFPA 101 - 40.3.1(2): “Approved existing open stairs, existing open ramps, and existing escalators shall be permitted where connecting only two floor levels.”
2. NFPA 101 - 11.2.3.2: “Open structures shall be exempt from protection of vertical opening requirements.”
3. NFPA 101 - 11.3.3.1.2: “In towers where the support structure is open and there is no occupancy below the top floor level, stairs shall be permitted to be open with no enclosure required, or fire escape stairs shall be permitted.”

The Fire Marshall determined that, while the total load of combustibles was low, it was possible that a fire producing dense smoke could be located adjacent to the stairs, due to the configuration of the platforms. As there was only a single means of egress planned for the building, this posed the risk that the only means of egress could be obstructed by a small, slow-growing fire located near the stairs. To mitigate this risk, the Fire Marshall determined the necessity of enclosing the existing staircase. As will be discussed further, this issue was revisited several times over the next 15 months as the contents of the building and the test operations were refined.

Based on this recommendation, the MSFC Facilities office instructed the A&E firm to include in the CoF Design the enclosure of the existing staircase but eliminate the second staircase, which had been included in the 50% PCD.

The third life safety issue identified by the Fire Marshall was whether or not a fire suppression system was required in TS4550. The Fire Marshall identified the following requirements:

1. NFPA 101 - 11.2.3.2: Open structures require an “automatic, manual or other protection that is appropriate to the particular hazard and that is designed to minimize danger to the occupants in case of fire or other emergency.”
2. NFPA 101 - 11.3.1.3.2: Towers require sprinklers if the levels below the observation tower are occupied and occupancy is limited.
3. NFPA 101 - 40.4: Sprinkler protection is not required for low-hazard, special-purpose industrial occupancies in high-rise buildings.
4. NASA-STD-8719.11, Paragraph 7.3.1, “Automatic sprinkler protection shall be provided for all new building/facility construction. Sprinklers shall be provided in renovation projects over 2,500 square feet (232.26 square meters) or involving over 50 percent of the building.”

As TS4550 is not an Open Structure or Tower as defined in NFPA 101, the first two identified requirements are not directly applicable. As demonstrated in the third identified requirement, even though other occupancies located in a high-rise building do require an automatic sprinkler system, NFPA 101 does not require one in high-rise, low-hazard, special purpose industrial occupancies. Similarly, the IBC does not specifically identify any special provisions for high-rise, low-hazard industrial occupancies in regards to fire suppression systems. Therefore, the fire and life safety codes do not require TS4550 to have an automatic sprinkler system.

However, NASA-STD-8719.11 requires a fire sprinkler system to be installed in TS4550, since over 2,500 square feet was being renovated. While the trigger threshold for the requirement in NASA-STD-8719.11 aligns with the similar provisions in NFPA 101 and the IBC for occupancy types other than Industrial, the NASA-STD-8719.11 requirement applies equally to all NASA buildings and occupancy types. In NFPA 101 and the IBC, similar requirements have the proviso that only the requirements specific to a particular occupancy type are made retroactive to an existing building. This means that for some occupancy types, a fire sprinkler system is not required even if the modifications exceed the trigger threshold. For example, NFPA 101 and the IBC do not require the installation of fire sprinklers in existing high-rise Industrial or Storage Occupancies. Consider also that NFPA 101 and the IBC do not require fire sprinklers in new Special Purpose Industrial Occupancies or new General Industrial Occupancies or Storage Occupancies with Low Hazard Contents; therefore, under the fire and building codes, even if TS4550 was a new construction, it would not be required to have a fire sprinkler system installed. For reasons not illuminated in the standard, NASA-STD-8719.11 imposes the much more stringent requirement that all new buildings and all existing buildings with significant renovations will be installed with fire sprinklers.

In the specific case of TS4550, the NASA-STD-8719.11 requirement would have provided negligible fire hazard risk mitigation, while at the same time imposing a significant financial burden upon NASA. It would have also adversely impacted the IVGVT project timeline, which in turn would have delayed First Flight of the Ares I.

The financial burden would have been the result of the significant technical challenges in designing and installing a fire suppression system in TS4550. As TS4550 is effectively a 15-story "tin shed" with no air conditioning, a fire sprinkler system would have had to be a dry pipe system. Due to the trip time limitations imposed by the building height, the dry pipe system would have to be broken up into multiple application zones with multiple dry valves located periodically through the building. The wet pipe risers to these dry pipe valves would have to be protected from the ambient conditions by weather resistant, insulated, conditioned, and fire resistant chases. Due to the building height, large fire pumps would be required to pump the water throughout the building. Both the fire pumps and the dry pipe valve assemblies would have to be located in weather resistant, insulated, conditioned, and fire resistant rooms. Additional conductors would have to be run to the building to supply the fire pumps, and power to the dry pipe valve air compressors would have to have been installed in weather- and fire-resistant chases. As the interior structure of TS4550 was an open grid work of steel columns and beams, all of the sprinkler heads would have to be installed in heat collecting shields so that they would properly actuate. As the roof panels above the atrium-like core were removable, any sprinkler piping attached to the roof panels would have to be designed to be disconnected from the residual of the system.

Due to the technical and installation issues, preliminary estimates from the A&E firm indicated the cost of the sprinkler system would be at least \$2M. This cost was not included in the original CoF or IVGVT budgets and would have to come out of Program reserves if an alternative solution could not be determined. In the face of the Task's financial constraints, the Fire Marshall indicated he would support the Test Conductor's variance request to NASA Headquarters to waive the NASA requirement for a fire suppression system if certain operational controls were put in place. These operational controls included strict control of combustibles in TS4550, exclusion of high hazards in and around TS4550, and limiting the maximum occupancy to 25 people. The Test Conductor agreed to incorporate the operational restrictions into his plans, and thus the MSFC Facilities Office did not include the design of a fire suppression system in the CoF Project. The response to the Test Conductor's request to NASA Headquarters S&MA for a variance to NASA-STD-8719.11 had not been received at the time the IVGVT Task was terminated.

RESPONSE TO FIRE MARSHALL'S INITIAL ASSESSMENT

After receiving direction from the MSFC Facilities Office as to the path forward, the A&E firm revised the PCD to include enclosure of the existing stair but eliminated the requirements for a second stair and a fire suppression system. After acceptance of the submitted PCD by the Facilities Office in May 2007, the A&E firm began preparing design documentation and project cost estimates.

When it became apparent in late June 2007 that the cost of enclosing the existing staircase was much greater than the available funding (approximately double the original CoF budget), FITO requested that the NASA specialty contractor with Life Safety Code expertise perform an independent evaluation of the life safety-related egress requirements of TS4550. The goal of this evaluation was to determine if the hazards specific to the IVGVT were such that enclosure of the existing staircase was a value-added activity. FITO also requested that the NASA contractor work with the Fire Marshall and the Facilities Office to assess lower cost alternatives to enclosing the existing staircase. The NASA contractor prepared an independent assessment which concurred with the Fire Marshall's assessment of the applicable codes, but suggested that enclosure of the existing staircase would not provide significant occupant risk reduction as the contractor was unable to determine a credible fire scenario which would preclude the building occupants from utilizing the existing open staircase⁴. This determination was based

on the fact that the building was constructed of non-combustibles, the test articles were effectively non-combustible, and the only transient combustibles introduced into the building would be limited to what a single individual could transport on a laboratory cart for purposes of instrumentation of the test articles.

After the Test Conductor and the FITO IVGVT Task Lead concurred with the preliminary assessment of the fire hazards, the NASA contractor discussed with the Fire Marshall what information would be required to substantiate a waiver of the enclosure requirement. The Fire Marshall indicated that the Test Conductor would have to provide a detailed fire hazards assessment that demonstrated that there were no credible fire scenarios that would imperil the building occupants. The Fire Marshall suggested that, in the event that sufficient fire hazard data could not be compiled in a timely manner, it would be prudent for the IVGVT Team to continue to prepare design documents for a protected means of egress from TS4550. The Fire Marshall agreed with the suggestion that an acceptable alternative to enclosing the existing staircase would be to build a second, open staircase on the exterior of the building. The Test Conductor requested the Facilities Office to direct the A&E firm to prepare an estimate for this option in lieu of enclosing the existing staircase, while the Engineering Directorate compiled the data necessary to support a complete fire hazards assessment.

As directed by the Test Conductor, the NASA contractor had also evaluated, and subsequently discussed with the Fire Marshall, lower-cost alternatives to enclosing the existing staircase. The first alternative discussed was to leave the existing staircase unmodified and provide a second staircase on the exterior of the building, segregated from the building by fire barriers. As previously indicated, this was the Fire Marshall's preferred alternative to enclosure of the existing staircase. Other alternative egress options were also discussed, including escape slides, rescue line descenders, and escape poles. These concepts were ultimately rejected due to the potential for occupants to be located on all floors of the building and the additional training requirements necessary to qualify the occupants to use the alternative egress devices. Alternatives to fully enclosing the existing staircase, such as draft curtains located at each level, were also considered, but the open nature of the structure and the uncertainty regarding what would be the highest level used by the building occupants precluded these options. The concept of areas of refuge was also considered but eliminated, due to the fact that the local fire departments did not have rescue apparatus of sufficient height to reach all floors of the building. The possibility of combining the areas of refuge concept with the concept of escape poles located on the exterior of the building was considered to have potential, but was eliminated when it was determined that the cost exceeded that of a second staircase.

AMMONIUM PERCHLORATE LEACHING ISSUE

As part of gathering data to support a complete fire hazards assessment, the IVGVT Task Lead requested information from the Ares Elements on the materials and products used in the construction of the test articles they were providing. In August 2007, the Ares First Stage Office provided a draft Hazards Analysis for the H-18 Inert Propellant, which the Inert First Stage Test Article Segments would be loaded with⁵. The draft Hazards Analysis stated:

While the H-18 propellant is considered safe for normal handling and even for abnormal events that would be catastrophic to live propellant, there are some concerns with the [Ammonium Perchlorate (AP)] oxidizer content. AP is very hygroscopic and will readily absorb moisture. On occasion, composite propellant rocket motor propellants that have been exposed to high humidity situations from

environmental exposure or standing water have had AP leach out of the bulk propellant and crystallize on the surface. That is a possibility with H-18 propellant as well. AP crystals on the surface could create a more reactive surface or crystals could be displaced and create additional hazards. The motor segments must be enclosed and desiccated except when the propellant has to be exposed.

Because Huntsville, Alabama is considered a high humidity environment and the report did not identify the rate at which AP could migrate to the surface of the inert propellant, the Fire Marshall was forced to assume that sufficient pure AP could leach to the inert propellant surface during the period the segments would be located at MSFC, thus acting as an ignition source for the bulk inert propellant itself. This concern was magnified by an Ares First Stage Office video, where a sample of H-18 was exposed to the flame of a hand-held blowtorch. While the video demonstrated empirically that H-18 would not sustain combustion without an external heat source, it also demonstrated that H-18, while smoldering, produces copious amounts of dense, dark smoke. The Fire Marshall was concerned that if an external fire or a quantity of pure AP started, the inert propellant smoldering the amount of smoke produced would obstruct the existing egress paths. The Fire Marshall informed the IVGVT Task Lead and the Test Conductor that unless this hazard could be mitigated or eliminated, he could not consider the building contents to consist of low or ordinary hazards, and, in addition to enclosure of the existing staircase, he would have to require the construction of a second staircase to provide a second means of egress.

The IVGVT Task Lead relayed the Fire Marshall's concern back to the Ares First Stage Office, which in turn relayed the concern back to the First Stage Contractor who revised the final draft of the H-18 Hazards Analysis to state:

While the H-18 propellant is considered safe for normal handling and even for abnormal events that would be catastrophic to live propellant, there are some concerns with the AP oxidizer content. AP is very hygroscopic and will readily absorb moisture. On occasion, composite propellant rocket motor propellants that have been exposed to high humidity situations from environmental exposure or standing water have had AP leach out of the bulk propellant and crystallize on the surface. AP crystals on the surface could create a more reactive surface or crystals could be displaced and create additional hazards.

Specific AP crystallization incidents have involved [the manufacturer of the] rocket motors provided for the Minuteman, Poseidon, Titan, and Delta II GEM programs. That is a possibility with H-18 propellant as well. However, the author is unaware of any such incidents involving H-18 inert propellant. Liquid water will of course dissolve and extract the AP. Relative humidity exposure above 75% RH is needed to deliquesce and recrystallize AP out of the binder matrix. Any extended high humidity exposure for more than a working shift should be avoided. The motor segments must be enclosed and desiccated except when the propellant has to be exposed. A typical [First Stage Contractor] requirement for live composite propellant rocket motors is to use a desiccant closure equipped with a humidity indicator and to change the desiccant before the internal relative humidity reaches 30%.

The conundrum this hazard analysis presented to the Fire Marshall was that, while the authors of the hazard analysis could not identify a single case where leaching of AP to the surface of the inert propellant had occurred, they stated there was the potential for this to occur. This was not a trivial issue, as the consequences of the AP leaching to the surface would increase the potential for the bulk inert propellant to be ignited, which, if that were to occur, would

produce copious amounts of smoke, obstructing the single exit from each level. The only documented control for this leaching was a manual operation, which could not be relied upon to protect the occupants in lieu of the required second means of egress. In response to this new hazard, the Fire Marshall revised his previous assessment and determined that in addition to enclosing the existing staircase, a second means of egress must be provided.

RESPONSE TO THE AMMONIUM PERCHLORATE LEACHING ISSUE

Working together with the Facilities Office and the A&E firm, the Test Conductor and FITO IVGVT Test Lead assessed the impact of adding both the enclosure of the existing staircase and the second external staircase to the Task budget and schedule. It was determined that the expansion in the scope of work would result in several million of dollars of additional costs, which was at least twice the approved CoF budget. It was also determined that, even if funding was immediately available, the potential existed that the construction effort would be so protracted that it might be impossible for the test to produce data in a timely manner. In addition, if the Project or Program was unable to fund the expanded scope of work, the CoF funding approval process could delay inauguration of the work by two or more years. As the impacts exceeded the Test Conductor's budget and schedule authority, the problem was elevated to the FITO IVGVT Task Lead for evaluation and direction while the Test Conductor attempted to find funding and resources from within the Engineering Directorate. Likewise, the Facilities Office began assessing the available Center funds, as well as funds allocated to other CoF projects, to determine if any could be applied to the TS4550 CoF project. In parallel to these efforts, the Facilities Office directed the A&E firm to prepare a design that would comply with the Fire Marshall's re-assessment of the situation to minimize potential schedule impacts.

The IVGVT Task Lead recognized two potential solutions to the funding problem. First, the increased scope of construction work would be funded either through the Project Office or by the Center. While the Test Conductor and Facilities Office worked at getting additional funding from the Center, the FITO IVGVT Task Lead began working the funding avenues available within the Cx Project. As previously mentioned, the Program was already under severe funding constraints and the initial inquiries along these lines brought the value of the IVGVT under scrutiny. The IVGVT Task Lead, with support of the Test Conductor and other members of the Engineering Directorate, spent the next several months proving that the risk reduction provided by the IVGVT to the Project was commensurate with the budgeted costs. This request for additional funding was still under consideration by the Project when the second potential solution to the problem was realized, rendering the request for additional funding moot.

The second potential solution was to eliminate the hazard that was predicated the change in scope. After consultation with members of the IVGVT Team, it was decided to approach this from two directions. First, as it was impractical from an operational perspective to desiccate the interior of the First Stage Test Article once it had been stacked, it was decided that the Engineering Directorate would devise a means of excluding humid air from the inert propellant core. Second, the FITO would work with the Ares First Stage Office to determine if there was either a means to prevent the AP from leaching to the surface of the propellant core, or if the amount of AP which could leach to the surface of the propellant core would be insufficient to ignite the bulk inert propellant. Through the Ares First Stage Office, the First Stage Contractor proposed that a test program be conducted, which would assay the changes in composition of the inert propellant loads located at sites around the country. These inert propellant loads included some inert propellant loads that were over 30 years old.

Personnel from the Engineering Directorate considered several methods for excluding humid air from the inert propellant core, which included blowing dry air across the core and pulling a partial vacuum on the core. The test engineers decided the most effective way to exclude humid air from the core was to provide a charge of gaseous nitrogen at a slight positive pressure to the core. This would prevent any water from entering the core after the First Stage Test Article was integrated and thereby prevent any AP from migrating to the inert propellant surface. Operationally, the core would be inspected for AP deposits before integration and, if any were discovered, they would be removed utilizing the processes developed by the Kennedy Space Center for removing AP deposits from live propellant loads. The only significant engineering challenge identified regarding the use of an inert gas (GN2) to inert or safe the First Stage Inert Segment Test Articles was the need to provide a means to monitor the system losses and ventilate the test stand if there was a buildup of nitrogen gas in the building. By spring 2008, a preliminary design had been prepared and reviewed by representatives of FITO, the Engineering Directorate, and S&MA. In April 2008, the Fire Marshall agreed that the proposed mitigation scheme would minimize the likelihood of AP leaching to the surface and, in conjunction with assurances that powered vehicles, which were not DOD certified for use around ordinance, would be excluded from the base of TS4550, he agreed that no modifications to the existing egress system was necessary. The Facilities Office then directed the A&E firm to eliminate the enclosure of the existing staircase and the new exterior staircase from the design saving time and funds.

FINAL SOLUTION TO THE LIFE SAFETY ISSUES

While the use of gaseous nitrogen to inert or safe the inert propellant eliminated the costs associated with modifying the building, it was not an ideal solution due to its imposing direct and operational costs upon the Task. The direct costs included those associated with designing and installing the nitrogen system and the building monitoring and ventilation system. In addition, as there would not be sufficient internal pressure (normally generated by the combustion process) to fully engage the segment-to-segment seals; it was assumed that the seals between the First Stage Test Article Segments would leak. This meant that the Task would have to pay for replacement nitrogen gas for the duration of the test program, which could span several years from initial integration to final disassembly. The expected operational costs were the result of test personnel having to monitor the building atmosphere for several years and work around a pressurized vessel during test operations.

The use of gaseous nitrogen also imposed the safety risks that (1) the building occupants could be exposed to hazardous levels of nitrogen gas in the building atmosphere and (2) those personnel were working around a pressurized test article.

For these reasons, the FITO IVGVT Test Lead and Engineering Directorate continued to support the work by the First Stage Contractor to assay the chemical composition of historical inert propellant loads, which included several that had been under water as well as the MVGVT Inert Solid Rocket Booster test articles stored at MSFC since 1979. By May 2009, the First Stage Contractor had compiled sufficient data from the historical inert propellant loads to definitively state that AP leaching would not occur with the H-18 inert propellant. The First Stage Contractor determined that, unlike the live propellant, in H-18 other compounds would preferentially leach to the surface of the inert propellant, forming a water proof barrier (effectively a glaze) on the surface. This barrier prevented any water from reacting with the AP and drawing it to the surface. The First Stage Contractor determined that this barrier formed shortly after casting and would rapidly re-form if disturbed. The possibility of AP leaching to the surface was highly improbable. The Ares First Stage Office and the First Stage Contractor presented this information to the Fire Marshall for consideration. In June 2009, the FITO IVGVT Task Lead and the Test Conductor

were informed by S&MA that the Fire Marshall had concurred with the findings of the First Stage Contractor's study and that it was no longer necessary to utilize a gaseous nitrogen system to prevent AP from leaching to the surface of the First Stage Test Article Inert Segments.

SUMMARY AND RECOMMENDATIONS

While appropriate reuse of existing test facilities is a fiscally responsible activity for projects, Project Managers need to be aware of the risks associated with reuse of test facilities. Just because a test facility complied with the regulations and standards in place at the time it was built or last modified, there is no guarantee that the test facility complies with current regulations and standards. Project Managers need to engage architects and architectural engineers in the early planning stages of a test program to minimize the impact of modifications to a test facility upon the project schedule and budget. Project Managers also need to remain engaged with the architectural process through the periodic design reviews so that, as issues arise, they can be addressed in a timely manner. Early in the lifecycle of the IVGVT, it was identified that some costs associated with upgrading TS4550 had not been included in the baselined budget. This could have been prevented by having a building code and safety review conducted before the project budget had been baselined. Once the building deficiencies were identified, all of the disparate member organizations which made up the IVGVT Team worked together to find a solution to the problem. When additional issues arose, the IVGVT Team evaluated the issues and found new solutions, which ensured the safety of the building occupants while remaining within the fiscal constraints imposed upon the Task.

When planning a future test program that involves the re-use of an existing test facility, it is recommended that:

1. Project Managers engage experts in the life safety regulations, fire codes, and building codes as early in the Project lifecycle as possible. Architects and architectural engineers should be considered stakeholders in the test planning equal to the test requesters and the test engineers.
2. Project Managers should engage the facility experts in the CoF process early to be sure that the facility will be available to meet testing needs.
3. Project Managers always assume during the initial planning stages that, if it is necessary to modify a test facility to accommodate the proposed test, the life safety features (i.e., egress paths, exit signage, fire alarm systems, and fire suppression systems) will have to be updated to comply with the current building codes. This assumption is particularly valid for previously mothballed or abandoned-in-place structures. This assumption may be invalidated during the preliminary architectural design phases and cost savings may be realized, but it is better to have a robust contingency fund than to have to prove that the occupant safety will not be compromised without upgrading the building.
4. Project Managers recognize that architects and architectural engineers will default to a prescriptive design based on strict adherence to the building codes and will only prepare a performance-based design if requested by the client.
5. Project Managers recognize that test engineers and architectural engineers use terminology and idioms which are specific to their discipline and background, and terms are not exclusive to a discipline. Project Managers should always ensure that when technical information is being discussed, all parties are defining the lexicon in the same way.

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IMAGE INDEX

1. Figure 1: NASA Technical Reports Server Image #7890776
2. Figure 6: NASA Technical Reports Server Images #7891971, 7992267, and 7992475